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An Essay on the VARIATIONS of the BAROMETER.

By RICHARD KIRWAN, *Esq; M.R.I.A. and F.R.S.*

AMONG the various pursuits which for upwards of a century have engaged the attention, and exercised the ingenuity of the philosophic world, none has the merit of contributing so largely to the general stock of natural knowledge, nor is there any from which mankind has derived such extensive and immediate advantage, as from that which has the nature and properties of the atmosphere for its object. To say nothing of the profound researches of a Scheele, a Cavendish or a Priestley, which have so happily developed the more secret and intimate qualities of this invisible fluid, it is from the investigation of its more general and obvious properties, its gravitation, density and elasticity, that mechanicks and astronomy have received many of their greatest improvements. The instrument which first led philosophers to suspect, and which at last fully confirmed the existence, and even defined the extent and limits of these properties, was the barometer. Through it the weight of the whole atmosphere which surrounds the earth,

Read March
1, 1788.

a problem which before its invention must have appeared far beyond the reach of human abilities, has been determined. It was this instrument, which in the hands of Otto Guericke and our immortal countryman Mr. Boyle, suggested the invention and improvement of the air-pump, and thus paved the way for the numerous discoveries to which this latter gave birth. To this instrument we stand indebted for our knowledge of the elasticity, condensation and rarefaction of the air; properties which have since been so happily applied to the construction and improvement of hydraulic machines, and the mensuration of heights. To it we owe a more accurate knowledge of the laws of the vibration of pendulums, and of those of the refraction of light; discoveries from which astronomy, and consequently navigation, have derived the greatest advantage. Nay, it may with truth be asserted, that it is to this instrument that modern philosophy owes its existence, and modern Europe its superiority over all other regions; for it was the Toricellian experiment that first demonstrated the futility of the antient mode of philosophising, and the advantages of experimental investigation, and thus excited the more civilized nations to those pursuits, which have since rendered them as superior both in arts and arms to the more ignorant, as men are to brutes.

GREAT, however, as has been the success attendant on the study and application of the observations made by the help of the barometer, the bulk of mankind have always expected still more from it: Nothing less indeed than a prognostic of the weather. Nor is this expectation entirely vain; particularly in the circumstance in which such foreknowledge is of most importance.

tance. The marine barometer, if we may credit the most respectable authorities, that of Doctor Halley*, Captain Middleton†, Lord Mulgrave‡, and many French navigators§, never fails to indicate a storm several hours before-hand. But with respect to less considerable changes of weather, it must be allowed that its variations afford no indications absolutely certain, though with certain restrictions they afford some ground for probable conjecture; and the reason of this difference is (as will more plainly appear in the sequel) because the height of the mercury in the barometer hath no immediate and necessary connexion either with rain or fair weather. That its variable height is the immediate consequence of the variable pressure of the atmosphere admits of no doubt, but the cause or causes of this variable pressure have not yet been fully ascertained; many indeed have been suggested, but none that reached the full extent of the phenomena. This acknowledged want of success of my predecessors in this enquiry, at the same time that it entitles me to make further researches in this intricate subject, will, I hope, plead my apology in case they prove equally unsuccessful. In order to lay the whole matter fully before the Academy, I shall first state the principal observations made on the variations of this instrument; secondly, the principal causes to which these variations have hitherto been referred, with a few remarks to shew the insufficiency

* IV. Phil. Transf. Abr. Part II. p. 6.

† VIII. Phil. Transf. Abr. p. 468.

‡ Phipps's Voyage, p. 74.

§ Encyclop. par Ordre des Matieres Navigation, tom. i. p. 112.

ficiency of these causes ; and lastly, I shall explain that which to me seems more adequate to the effect.

FIRST OBSERVATION.

THE more considerable elevations and depressions of the $\bar{x}$ in the barometer happen at a very short interval of time in places very remote from each other. This correspondence was observed by Mr. Derham in 1699 between the heights of the $\bar{x}$ at Upminster in Essex and Townley in Lancashire ; and afterwards by Mr. Maraldi, between the variations at Paris and Genoa *, at the distance of nearly four degrees of latitude. Mr. Derham also observed nearly the same agreement between barometers at Berlin, lat. 53° , and Pithæa, lat. 65° † ; as did Asclepi between those at Rome, lat. 42° , and at Padua, lat. 45° ‡. But I have remarked that where there is a considerable difference of longitude, the like agreement is not found. Thus Mr. Hadley found that at London and Padua the variations are frequently in opposite directions § ; and so they commonly are at Ponoï, lat. 67° , long. 47° E. and Peterburgh, lat. 60° long 30° E. ; and the discordance is still greater between the variations at Peterburgh and those at Jakutski, lat. 62° , long. 129° E. || ; Maraldi observed also that different winds prevailed at Paris and Genoa during the corre-

* Mem. Par. 1709.

† VIII. Phil. Transf. Abr.

‡ La Cotte Metereol. p. 181.

§ VIII. Phil. Transf. Abr. p. 587.

|| XIV. N. Act. Petrop.

ponding variations. On the other hand, variations in a contrary sense, but inconsiderable in their extent, are often observed in places very near to each other, as Franeker and Lewarden, as Mr. Van Swinden assures us *.

SECOND OBSERVATION.

THE deviations of the $\bar{x}$ from its mean annual altitude are far more frequent and extensive in the neighbourhood of the poles than in that of the equator. At Peterburgh, An. 1725, the $\bar{x}$ once stood at the stupendous height of 31,59 inches, if we may credit Mr. Confett; and yet it has been seen so low as 28,14 inches. In the northern parts of France the variations are greater than in the southern †; at Naples they scarcely exceed one inch ‡. In Peru, under the equator, and at the level of the sea, they amount only to two or three-tenths of an inch; but in other parts, within a few degrees of the line, on the approach of the rainy season or of hurricanes, the barometer falls an inch or more §.

THIRD OBSERVATION.

THE variations without the tropics are greater and more frequent in the winter than in the summer months. VIII. Phil. Transf. Abr. 605. La Cotte, 298.

* Observations sur le froid de L'année 1776, p. 55. VIII. Phil. Transf. Abr. p. 555.

† La Cotte, p. 186.

‡ VIII. Phil. Transf. Abr. p. 566.

§ Boug. Fig. XXXIX. Phil. Transf. 1778, p. 182. Hist. of Jamaica, Vol. I. p. 372.

FOURTH

FOURTH OBSERVATION.

THE variations are considerably smaller in very elevated situations than on the level of the sea. Thus Mr. Bouguer observed that while on the coasts of Peru the variations extended to $\frac{1}{4}$ of an inch; at Quito, elevated 9374 feet above the sea, they reached only to 0,083 of an inch. Mr. Sauffure made similar observations in Savoy, as did Mr. Lambert in Switzerland. II. Sauff. Voy. aux Alpes, p. 577.

FIFTH OBSERVATION.

THE mean height of the barometer on the level of the sea in most parts of the globe hitherto examined is about 30 inches. Mr. Bouguer under the line observed it at 29,908 inches; but as his barometer was not purged of air by fire, it stood lower than it should. Sir George Shuckburgh, on a mean of several observations on the coasts of Italy and England, found it at 30,04, when the temperature of the ☉ was 55° , and that of the air 62° . In the proximity of the poles the annual mean heights of the barometer differ much more from this standard than in the more southern parts of our hemisphere.

As to the connection of the variations of the barometer with the weather, the four following observations, made by Dr. Halley in England, seem to be most universal, as they were found by Mr. Melander to apply to lat. 39° *, and by Mr. De Luc to lat. 46° †.

* Schwed. Abhand. 1773, S. 255.

† 1 De Luc Modif. p. 77.

SIXTH OBSERVATION.

“ IN calm weather, when the air is inclined to rain, the $\bar{x}$ is
“ commonly low.”

SEVENTH OBSERVATION.

“ UPON very high winds, though not accompanied with rain,
“ the $\bar{x}$ sinks lowest, having regard to the quarter from whence
“ the wind blows.”

EIGHTH OBSERVATION.

“ IN serene and settled weather the $\bar{x}$ is generally high, as
“ also in calm and frosty weather.”

NINTH OBSERVATION.

“ THE greatest heights of the $\bar{x}$ are found upon easterly and
“ north easterly winds ; to which we may add, that under a
“ southerly wind it is commonly low.”

THE causes to which these phænomena have been ascribed,
are, first, variations of temperature ; secondly, the velocity and
other qualities of different winds ; thirdly, the agency of
vapors.

Of the Influence of different Temperatures.

THAT air is rarified by heat and condensed by cold is well
known ; and it is equally so, that dense air is heavier than that
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which is rarer; but then the masses must be unequal; for while they remain the same the weights must be equal, and consequently so must the heights to which they elevate the mercury. If, therefore, an alteration of temperature alters the height of the barometer, it must be by diminishing or encreasing the mass of the atmosphere. Now it appears by observation, that a variation of the mass of the atmosphere is not a necessary consequence of an alteration of the temperature; for the $\bar{x}$ is often at the same height at different seasons, and at different places in the same season; for instance, in winter, at London and Peterburgh, though the temperatures at those seasons and places be very different; and even when the height of the $\bar{x}$ changes simultaneously with the temperature, the change is often directly contrary to that which the change of temperature would lead one to expect. Thus on the 9th of January, 1777, at eight o'clock in the morning, the thermometer at London stood at 19° under a N. wind, and the barometer at 29,69; but at two o'clock in the afternoon, the wind being W. by S. the thermometer rose to 31,5, and the barometer to 29,7, instead of falling, as might be expected, from an encrease of 12,5 degrees of heat. Phil. Trans. 1778, p. 574.

BESIDES, great changes of temperature take place only in the lower atmosphere; in the higher regions they are inconsiderable. Now any increment or decrement of the mass of the lower atmosphere that can be ascribed to a change of temperature is too small to produce any considerable alteration in the height of the barometer; for in winter the height to which any considerable variation of temperature may be supposed to extend, scarcely

scarcely exceeds 5000 feet, as we learn from the testimony of aeronauts and the height of clouds; and indeed the winds that prevail on the surface of the earth, and which are the primary agents of a change of temperature, seldom reach higher, and in the more northern regions not so high. Thus, on the 1st of December, 1783, at Paris, while a S. wind prevailed below, a N. wind prevailed at the height of 1280 feet*; and the same opposition was found in the currents of air at the same height at Pisançon in January, 1784. At Ponoï the clouds are frequently seen unmoved during the most violent storms†; yet on the 21st of December, 1779, the thermometer in the open air being at 49°, and the wind S. S. E. the barometer stood at 28,91 inches; but the next day, the wind turning to N. N. W. the thermometer fell to 30°, and the barometer rose to 29,89 inches. Here the difference of temperature is 19°, and the variation of the barometrical height nearly $\frac{2}{10}$ of an inch. Let us now examine how this fact can be explained on the supposition that the mass of the lower atmosphere is increased in proportion to the condensation of its volume.

IN the first place, we may assume that heat in its progress upwards decreases nearly in an arithmetical progression. The barometrical method of measuring heights is in a great measure founded on this supposition; and as the errors of this method do not exceed 2 or 3 feet, and seldom 1 foot in 1000, it may be looked upon as sufficiently exact, and consequently so may the

* Mem. Par. 1782, p. 650.

† II. Faujas Balons, p. 274. XVI. N. Act. Petrop. p. 68.

supposition on which it is grounded. On examining a considerable number of observations of this sort, I find that the differences of heat at different elevations are to the differences of the logarithms of the mercurial heights at those elevations, very nearly, as 160 to 1; and the difference of the logarithms may be found sufficiently near, by dividing the elevation in feet by 60000. If then, in the instance above given, the S. wind reached the height of 5000 feet, the difference of the logarithms should be $\frac{5000}{60000} = .083333$, which multiplied into 160, gives 13°,33 for the difference of temperature at the surface of the earth and at that height; and the former being 49°, the latter must have been 35°,67, and consequently the mean temperature of the southern air 42,33. Again, supposing the N. wind to have obtained the same height, the temperature at the surface of the earth being 30°, that at the height of 5000 feet should be 16°,67, and the mean temperature 23,33; or in round numbers, the mean temperature of the southern current was 42°, and that of the northern 23°, and the difference of both temperatures 19°. Now 5000 feet = 60000 inches; and by General Roy's experiments*, it appears that 1000 parts of air at the temperature of 42° lose about 40 of their bulk by 19° of cold, and consequently 60000 should lose 2400. But as in this case the height of the column of air is supposed to be the same after condensation as before it, its mass or density must be increased by the addition of 2400 inches, which when the barometer is at 29,89, and the thermometer at 23°, weigh 762,36 grains; and as one-tenth of an inch of 8, even at the temperature of 62°, weighs 344,32

* Phil. Transf. 1777, Part II.

grains,

grains, it appears that the above accession of weight to the column of air that supports it can raise it little more than $\frac{2}{100}$ of an inch, instead of nearly $\frac{2}{100}$, the variation to be accounted for. This cause, therefore, though not absolutely inefficient on the supposition that the whole mass of the superincumbent column is increased by the accession of new air in proportion to the condensation, is notwithstanding inadequate to the effect produced.

Of the Influence of Winds.

THE winds, whose efficacy in producing the variations of the barometer I am about to discuss, are those which reign in the lower regions of the atmosphere, they being principally referred to by those philosophers who have had recourse to their agency.

FIRST. Doctor Halley attributes the rise of the barometer over its mean altitude to the accumulation of air over the place of observation, which accumulation he attributes to two contrary winds blowing towards that place; but if this were the cause of the elevation of the mercury, we should always have a calm when the $\bar{x}$ stands highest; for the accumulation should take place only when the two contrary winds blow with equal force, since if one of them prevails it should repel its antagonist, and it is only during the prevalence of neither that the air can be accumulated. Now it is notorious that the greatest mercurial heights are accompanied by an easterly or northerly wind, as he himself has observed. Nor can that equality of barometrical heights

heights which we have mentioned in the first observation to take place in very distant countries, in which very different winds prevail, be explained in this hypothesis. It is moreover flatly contradicted by the observation of Mr. Forth, who, while the mercury all over England stood lower than ever it was known to do, found that a N. E. wind prevailed in the northern part of that island, and a S. W. in the southern. VIII. Phil. Trans. Abridg. p. 497.

SECONDLY. In this hypothesis the descent of the $\bar{x}$ beneath its mean altitude is ascribed to the rarefaction of the atmosphere over the place of observation, owing to its exhaustion by two contrary currents ; for instance over England, if it should blow a westerly wind on the German, and an easterly wind on the Irish sea. But a rarefaction in such circumstances from such a cause seems to me impossible ; for if such currents took place, the northern or southern air would flow in to maintain the equilibrium in the same proportion ; or if this did not happen, and that four contrary currents took place, the higher air should descend, and cause a sensible cold, which yet is seldom observed in England when the $\bar{x}$ is low ; on the contrary, a warm S. wind commonly prevails, to whose temperature nevertheless the rarefaction cannot be ascribed, as we have already seen.

THIRDLY. The great descent of the $\bar{x}$ on high winds in storms is thus explained by Doctor Halley : “ The region of
 “ the earth wherein those winds rage, not extending round the
 “ globe, the stagnant air left behind, and that on the sides, cannot
 “ rush in fast enough to restore the evacuation made by so
 “ swift

“ swift a current, so that the air must be attenuated where the
 “ said winds continue to blow.”— “ Add that the horizontal
 “ motion, being so quick, may take off some part of the per-
 “ pendicular pressure.” This last reason seemed to acquire some
 confirmation from an experiment made by Mr. Hawksby; for
 having passed a stream of air through a box in which the lower
 flank of a barometer was inserted, this ingenious gentleman
 observed the $\bar{x}$ to fall while the current passed through the box,
 as also in another barometer which communicated with the box,
 but over which the current of air did not flow.

YET if all this were allowed, still the phænomenon in question
 would remain unexplained; for not only during the storm, but
 several hours, if not days before it, the mercury descends consider-
 ably, as Doctor Halley himself and all those who recommend the
 marine barometer attest, otherwise this instrument would be use-
 less. Mr. Caswell says that two days before the great storm of
 January, 1734-5, the $\bar{x}$ fell $\frac{1}{10}$ of an inch below 28 inches*.
 But even if the fall were barely concomitant with the storm,
 Doctor Halley’s reasons would not prove their connexion. That
 a body should move through air with such velocity as to leave
 a vacuum behind it, there is a necessity that it should move at
 the rate of 11 or 1200 feet per second, as Mr. Robins has shewn;
 now the swiftest wind moves only at the rate of 92 or 93 feet
 per second, as appears by the observations of Mr. Brice and
 many others†.

* VIII. Phil. Transf. Abr. p. 458.

† Phil. Transf. 1766, p. 266.

THE insufficiency of the second reason alledged by Doctor Halley has been clearly shewn by Mr. De Luc; nor is the experiment of Mr. Hawksby conclusive, as it appears that part of the air already confined in the boxes was forced out by the blast of air; and to remove all doubt of the insufficiency of this explanation, I need only mention the observation of Mr. Derham, that during the greatest vehemence of storm the $\bar{x}$ rises instead of falling lower. IV. Phil. Transf. Abridg. Part II. p. 77. And I have had occasion to make the same observation on the 28th of February, 1785, in London.

Of the Influence of Vapors.

THE influence of vapors was never totally overlooked by any of the philosophers who undertook to explain the variations of the barometer, though the part they really act was little understood by any except Mr. De Luc. However, within these few years the greatest light has been thrown on this subject by Mr. De Saussure, in his incomparable treatise on hygrometry. He very justly distinguishes two sorts of vapors; the *invisible*, to which the name of vapor is most properly applicable, and the *visible*; of this last there are two sorts, the *vesicular* and the *concrete*. The invisible are specifically lighter than air of the same temperature, as Mr. De Luc has shewn by numerous observations, and Mr. De Saussure by direct experiments; but the *vesicular* are of the same specific gravity as the air in which they subsist. To understand the influence of both species of vapors on the barometer, it is necessary to enumerate some of their principal properties, and shew how air is affected by them.

FIRST.

FIRST. Mr. De Sauffure and General Roy have proved that water in its solid state evaporates in every degree of cold between 0 and 32°, as it is well known to do in its liquid state, and in far greater proportion in all degrees superior to 32°.

SECONDLY. Though water evaporates more quickly and in greater quantity *in vacuo* than in open air (and consequently its evaporation cannot be attributed to its affinity to air) yet it would speedily be condensed back again into water by contact with colder bodies if it did not adhere to air, which therefore chiefly supports it in a vaporous state, and thus the different opinions of philosophers on this subject may be reconciled. Mr. Sauffure has shewn that the power of air to support vapor diminishes with its density, but not in the same ratio, even though the heat should continue unaltered. This power, therefore, depends partly on its temperature, and partly on its density; and hence invisible vapor abounds more in the lower than in the middle strata of the atmosphere. Mr. Lambert, in the memoirs of Berlin for the year 1772, has shewn that the quantity of vapor at different elevations in the atmosphere is generally as the squares of the mercurial altitudes at those elevations, which I believe to be true in all heights to us accessible; but in the very highest regions, which are occupied chiefly by inflammable air, I am inclined to think that vapor is more abundant than in the middle strata, as water adheres more strongly to this air than to respirable air, and it is probably this circumstance that gave rise to the great mist observed in 1783.

THIRDLY. To the delicate experiments of Mr. Sauffure we are also indebted for the interesting discovery that a cubic foot
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of air, when saturated with vapor in the temperature of 32° , contains about 4 grains of water, and gains 0,1109 of a grain by saturation at every degree between 32° and 80° , the barometer being at 28,77; so that at 66° it contains when saturated 7,7 grains of moisture, and about 8,7 if the barometer be at 30 inches*. I have often indeed found a greater proportion of moisture in a cubic foot of air than is here mentioned, but then it was on dark days, in which the air was not perfectly transparent, and consequently abounded in vesicular vapor.

FOURTHLY. The same excellent philosopher has discovered that in the temperature of 65° , the elasticity of air which passes from a state of absolute dryness to that of saturation with moisture, is increased $\frac{1}{54}$, or as I compute $\frac{1}{51}$; and hence he infers that the weight of vapor is to that of air of the same temperature as 10 to 14; however, as the weight of common air appears by my own experiments to be much lower than he supposes it, I conclude the weight of vapor to be to that of common air as 10 to 12. Mr. De Luc, reasoning from Mr. Watts's experiments, makes the ratio much greater; but as those experiments were made on vapor in a boiling heat, they do not appear to me to warrant that conclusion. The elasticity of vapors differs much from that of air in this respect, that any considerable accession of pressure will reduce them in some degree to the state of vesicular vapor, particularly if they are nearly in a state of saturation in the compressed air.

* The weights and measures are reduced to the English standard.

FIFTHLY.

FIFTHLY. Vesicular vapor consists of a number of hollow visible globules, highly electrified *, and devoid of elasticity. It forms a sort of middle state between water and invisible vapor, and when in large quantity forms *mists* and *clouds*; when in small quantity it barely diminishes the transparency of air. It cannot subsist for any time but in air saturated with invisible vapor, from whose decomposition it arises.

SIXTHLY. The condensation of vapor arises not merely from cold, but from cold and contiguity, otherwise vapor could not be formed in a temperature below the freezing point.

FROM this view of the nature of vapors, and the change they produce in the weight and elasticity of the atmosphere, it is plain that their presence or absence cannot fully account for the variations of the barometer. For if we suppose the atmosphere perfectly dry, the barometer at 30 inches, and the thermometer at 65° , and then a column thereof to be saturated with moisture, its elasticity being increased $\frac{1}{31}$, it will contain $\frac{1}{31}$ of its volume less air than before saturation, since the increase of its elasticity arises from the introduction of a new elastic fluid amounting to $\frac{1}{31}$ of its bulk: And since the weight of the whole volume was at first equal to that of 30 inches of $\frac{1}{31}$, its weight will now be lessened by $\frac{1}{31}$ of 30 inches, that is nearly 0,59 of an inch. But on the other hand it gained $\frac{1}{31}$ of its volume of vapor, therefore its real loss of weight will be the difference of the weight of $\frac{1}{31}$ of air, and $\frac{1}{31}$ of vapor; but the weight of air is to that of

* II. Sauff. Voy. aux Alpes, p. 259.

vapor as 12 to 10, therefore the gain here is 0,49 of an inch, which deducted from 0,59 the loss, leaves the loss $\frac{1}{10}$ of an inch. This, therefore, is the variation the barometer should undergo by the passage of a column of air from absolute dryness to complete saturation, a circumstance which perhaps never takes place, as the atmosphere is never absolutely dry; and yet previous to heavy rains we often observe the barometer to fall 3, 4 or 5-tenths of an inch, a fall which we see cannot originate from the saturation of the atmosphere with vapor. Nor is there any proportion between the ascent of $\bar{x}$ after heavy rains and the weight of vapor condensed, for in such cases the $\bar{x}$ frequently rises 3 or 4-tenths of an inch; and yet the heaviest rain seldom produces one cubic inch of water, and the weight of a cubic inch of water is not equal to that of even $\frac{1}{10}$ of a cubic inch of $\bar{x}$.

Of the unequal Diffusion of the higher Atmosphere.

HAVING thus shewn the insufficiency of those causes to which the variable weight of the atmosphere and height of the barometer have been usually referred, I now proceed to explain that which alone seems to me adequate to the effects produced; namely, the accumulation of air over those parts of the globe in which the mercury exceeds its mean height, that is the height suited to its situation, and the diminution or subtraction of the natural quantity of air over those regions in which the $\bar{x}$ falls beneath its mean height. To trace the origin of this accumulation and diminution we must consider what may be called the natural state of the atmosphere, and how this state is disturbed.

I call

I call that state the natural state of the atmosphere in which the barometer on the level of the sea would stand at 30 inches in serene weather, conformably to the fifth observation. To produce this state, the weight of the atmosphere must be every where equal at the surface of the sea. The weight of the atmosphere proceeds from its density and height; therefore, to produce this equality of weight, it should be lowest where its density is greatest, and highest where its density is least. These extremes of density take place in the æquatorial and polar regions. Under the æquator, the centrifugal force, the distance from the centre of the earth, and the heat, are all at their *maximum*; in the vicinity of the poles, on the contrary, they are at their *minimum*. Therefore, if the height of the γ be 30 inches under the æquator and under the poles, the atmosphere must be highest under the æquator, and lowest under the poles, with several intermediate gradations.

BUT though the æquatorial air be less dense to a certain height than the polar, yet at certain greater heights it must be more dense; for the mercurial heights at the level of the sea being equal, the masses of the corresponding atmospheric columns must be equal; but the lower part of the æquatorial column being more expanded by heat, &c. than the corresponding section of the polar column, its mass must also be smaller than that of the corresponding section of the polar column; therefore a proportionably greater part of its mass is found in its superior section than is found in the superior section of the polar column; therefore the lower extremity of the superior section of the æquatorial column is more compressed, and consequently denser than
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the lower extremity of the superior section of the polar column. What is here said of the æquatorial and polar columns must be understood also of the extratropical columns with respect to each other, where great differences of heat prevail.

HENCE, in the highest regions of the atmosphere, the denser æquatorial air not being supported by the collateral extratropical columns, gradually flows over, and rolls down to the north and south.

THESE superior tides consist chiefly of inflammable air, as it is much lighter than any other, and is generated in great plenty between the tropics; it furnishes the matter of the *Aurora Borealis* and *Australis*, by whose combustion it is destroyed, else its quantity would in time become too great, and the weight of the atmosphere annually encreased; but its combustion is the primary source of the greatest perturbations of the atmosphere, as will presently be shewn.

IF the affluence of the northern and southern air to the æquator by the trade winds kept pace with the effluence of the superior air, an æquilibrium might still in some measure be maintained. But the trade winds move only at the rate of twelve feet per second, or about eight miles an hour*; whereas, without the tropics, or at least beyond latitude 30°, the currents of the upper atmosphere are incomparably more rapid†. For as the

* H. Bergm. Erdeklatet, p. 116.

† Sauff. Hygr. 300. I. Gentil. Voy. aux Indes, p. 486.

mean heat of the whole space between lat. 0 and lat. 30° is only seven degrees less than the mean heat under the æquator, the difference of density is not so great as to cause any rapid collapſion of the ſuperior columns within that ſpace; but from lat. 30 to lat. 60° (a much ſmaller ſpace) the mean annual heat over the ocean differs from that of lat. 30° by nearly fourteen degrees *; therefore the rapidity of the upper current towards the polar regions is much greater, and frequent interruptions muſt take place, during which the weight of the atmosphere will be diminished. And hence, notwithstanding the high winds that frequently prevail between the tropics, the barometer varies inconfiderably and but ſeldom, whereas without them the variations are frequent and conſiderable, nearly in proportion to the diſtance from the æquator; and thus the ſecond obſervation is ſufficiently explained.

As the tides of the ſuperior atmosphere flow in greater quantity where they meet with leaſt reſiſtance, the direction of this *maximum* of quantity is different in different ſeaſons of the year, and on different places.

DURING the ſummer of the northern hemisphere, as winter then prevails in the ſouthern, the density of the æquatorial air becomes ſuperior to that of the ſouthern air at a much lower height than that at which it becomes ſuperior to the northern, which is itſelf expanded by the preſence of the ſun in the northern tropic; therefore the ſuperior exuberance is chiefly

* Eſtimate of the Temperature of different Latitudes, p: 17.

poured on the southern regions, and a comparatively smaller quantity flows over the northern; therefore the variations of the barometer are smaller with us in the summer season, according to the third observation, and fewer auroras are formed.

As the tops of the highest mountains are covered with snow even in summer, the air over them will remain colder than that over plains, and its columns shorter; and hence the superior air in its passage to the poles will linger and accumulate over them, until the difference of density becomes so great as to enable this air to burst through the hot air that surrounds it, and form cold winds that raise the barometer in this season.

In winter, on the contrary, the superior current is chiefly directed to the northern hemisphere, and hence the greatest mercurial heights are found in this season. It accumulates where the columns of the inferior air are coldest, and consequently shortest; that is to say, over all that part of Asia beyond lat. 35, and E. of the Caspian Sea to the Frozen Ocean, and over the continent of North America, which I have elsewhere shewn to be colder than the old continent, and over the polar regions. Hence the barometer usually stands higher in North America, and varies less than with us* even in Hudson's Bay, lat. 59, where the weather is so turbulent the barometer varies but 1,37 inches, whereas in Peterburgh it varies above two †.

* II. Phil. Transf. Philad. p. 142.

† Phil. Transf. 1770, p. 148.

THE denser air of the North American continent pressing on the rarer incumbent on the Atlantic, produces the almost constant westerly winds which prevail on the eastern coasts of America*, and in the western parts of Europe below lat. 70° ; but above that parallel the superior European current passes by a shorter way into America, where the cold is greater.

ACCUMULATIONS are also formed in the southern parts of the old continent; for instance, over the mountainous tracts of Thibet, Tartary, Turkey in Europe, Africa, and even in some degree on the Pyrenees and Alps; when the rarefaction in the northern parts of Europe is frequent and considerable, either from the passage of the northern air to America, or from frequent and considerable auroræ borealis, the southern air flows from these tracts to restore the æquilibrium; and while this current lasts, and until the æquilibrium is restored, the barometer must fall in the intermediate regions; so that the descent of the $\bar{x}$ is never the effect of a southerly wind, but both it and this wind are concomitant effects of a rarefaction in the northern parts, proceeding from the causes already mentioned.

ON the other hand the $\bar{x}$ generally rises under a northerly or easterly wind, because, as I have already said, the superior atmosphere is accumulated chiefly in those parts of our hemisphere from whence these winds issue, and this accumulated air passes with them to the southern regions. A certain proof that this accumulation is the true cause of their superior density is, that

* II. Phil. Transf. Philad. p. 99.

when this northerly wind is furmounted by a S. W. the $\bar{x}$ falls; as the southerly wind in the superior regions procures a rarefaction in the superior or northern traëis. See Mr. Derham's observations, IV. Phil. Transf. Abr. Part II. p. 71; and that mere cold is no way concerned in the variation caused by this wind appears in various instances, to which I refer in the notes *.

IN the same manner when the $\bar{x}$ falls previous to a storm, both the storm and this fall proceed from a great rarefaction in the air in the quarter towards which the storm blows; which rarefaction proceeds from the diminution or destruction of the superior atmosphere.

As the superior accumulation is derived to us chiefly from North America, where it most frequently arrives at its *maximum*, hence it is, that the variations of the barometer generally begin to the westward with us in Europe, and are thence gradually propagated eastward (as Mr. Planer observed on comparing those of London and Vienna †) and comprehend nearly at the same time distant degrees of latitude, but not of longitude, according to the first observation; as the appulse of the superior accumulation to the European shores may be extensive, but its propagation eastward must be progressive. In spring the current of superior air begins to flow to the south, and in autumn to return

* II. Phil. Transf. Abr. p. 4, 61, 62. VIII. Ditto, p. 614. Phil. Transf. 1778, p. 574. Mem. Par. 1709, p. 302, in 8vo.

† II. Ephem. Palat.

from

from it; hence the equinoctial storms and frequent variations of the barometer in those seasons.

THE quantity of æquatorial air devolved on our hemisphere in different years is variable, and so is the quantity consumed in the northern regions; hence the mean barometrical height is different in different years. A set of observations on the changes that take place between the tropics in different years, compared with those that happen in northern and intermediate regions, would remove all the obscurities that attend a minute consideration of this subject. Barometers in the middle latitudes might apprise us of the quantity of air derived to our hemisphere, and those in polar regions might inform us of the quantity consumed; but as these observations have not been yet made, we must content ourselves with a general view of what appears to be the principal cause of these different annual variations.

IN some years the accumulation resting on the mountainous countries of the south of Asia and Europe, and the northern part of Africa, is greater than in other years, owing perhaps to a greater or earlier fall of snow; when this happens the northern air is lighter and the southern colder than usual, and south winds principally prevail, which, in the northern parts (usually subject to far greater cold) must appear comparatively warm; hence, when the winter is remarkably severe in the south of Europe and Asia, it is often as remarkably mild in the northern parts, and the barometer low.

THOUGH clouds and a disposition to rain frequently follow the descent of the $\bar{x}$, yet this descent is not the immediate consequence of either clouds or rain ; on the contrary the $\bar{x}$ frequently rises during rain. But the rarefaction of the atmosphere which produces the descent of the $\bar{x}$, and which arises from the removal of the superior accumulation, is favourable to the production of clouds, as a heavy atmosphere, though it supports vapors once formed, obstructs evaporation ; when, therefore, its weight is diminished, and evaporation encreased, it soon becomes saturated in the higher regions, and clouds are formed. But rain seems to arise from a subtraction of the electrical fluid, which, when the air abounds with vapors, is easily conducted to the earth. In serene and settled weather the $\bar{x}$ is generally high, because the greatest disturbances of the atmosphere are connected with its rarefied state, which is commonly pretty distant when the superior accumulation is considerable.

THAT the variations of the mercurial heights should be greater at the level of the sea than at great elevations above that level is very natural. For supposing the $\bar{x}$ at the level of the sea to stand at 30 inches, and at a certain elevation above that level at 25 inches, then if the weight of the atmosphere be diminished $\frac{1}{100}$ part, the $\bar{x}$ at the level of the sea should fall $\frac{1}{100}$ part of 30 inches = 0,3 of an inch, but that on the elevation should fall $\frac{1}{100}$ of 25 inches = 0,25 of an inch ; but it has been observed that the variation on high mountains is beyond all proportion smaller than on the level of the sea, which proceeds from a cause hitherto unnoticed, yet deserving the greatest attention ; namely, a property which they seem to possess of condensing and
accumulating

accumulating the air incumbent on them in a greater degree than the air incumbent over plains is condensed at equal heights; and hence when the barometer on the plains falls, and that on the mountain also, it will be found, after making allowance for the difference of temperature, that the fall is proportionably greater in the inferior than in the superior barometer; and on the contrary, if the $\bar{x}$ ascends both in the inferior and superior barometer, the ascent will be proportionably greater in the superior than in the inferior.

Thus General Roy on the 7th of August, 1775, at nine o'clock, found the *correct* height of a barometer on Carnarvon quay 30,075, and on the peak of Snowden 26,418 inches. At twelve o'clock that on the quay fell to 30,043, and that on the peak to 26,405; the fall of the $\bar{x}$ on the plain was therefore $\frac{1}{1002}$ of the whole, and the fall on the mountain was only $\frac{1}{2032}$ of its original height. On the other hand, at two o'clock, the barometer on the quay rose to 30,045, while that on the peak rose to 26,415 inches *correct* height; therefore that on the quay ascended only $\frac{1}{5021}$ of the whole, whereas that on the peak ascended $\frac{1}{2640}$ part of its height. Yet as the descents of the $\bar{x}$ beneath its most usual mean height are much more frequent and considerable than its ascents above it, the variations on mountains are upon the whole proportionably smaller than at the surface of the sea. I am sensible that some observations occur in which the $\bar{x}$ has been found to fall on mountains while it ascended on the plains; but in all those I have met, this happened in warm sunny weather, on rocky summits which were heated in far greater proportion than their height demanded,

demanded, and thus rarefied the air in contact with them; or on windy days, which did not permit the air to stagnate; or when a southerly wind prevailed above and not below. It was from a condensation of this sort, apparent in the mensuration of Hackluyt-hill in Spitsbergen, that General Roy inferred that the polar air, though affected with the same temperature and pressure, was specifically heavier than in the middle zones, which cannot be strictly true, as certainly the polar air must by the many storms that have blown to and from it, be long ago mixed with the common mass of the atmosphere.

I MUST admit that the justly celebrated Bouguer was of a contrary opinion; for, from some experiments made with a pendulum, he concluded that air on the highest mountains was proportionably more elastic and less dense than that on the surface of the earth; but one of his comparative experiments on which he rested this conclusion, was made in the moist air of Popayan, with a pendulum made of the fibres of the aloe leaf; and I have been assured by a very competent judge both of hygrometers and pendulums*, that this vegetable sensibly attracts moisture; so that its weight being encreased, it is not surprising that its vibrations were retarded in greater proportion than they otherwise would be.

As I have all along supposed the rarefaction of the atmosphere in the polar regions to proceed from the auroræ borealis and australis, which I take to be a combustion of inflammable

* Mr. Whitehurst. See also Herbert de Igne, p. 18.

air caused by electricity, I shall conclude by stating the facts on which this supposition is founded.

FIRST. It is certain that inflammable air is produced, particularly between the tropics, by many natural operations, such as the putrefaction of animal and vegetable substances, volcanoes, &c. and that this air is lighter than any other, and consequently occupies the highest regions of the atmosphere; and hence Mr. Sauffure and others have found the air on the highest mountains less pure than that on the plains, and its electricity stronger.

SECONDLY. It is allowed by Doctor Halley and others who have treated of the trade winds, that the highest air between the tropics is thrown off on both sides towards the poles, and of this I think I have given sufficient proof; therefore it is inflammable air that is chiefly thrown off towards the poles.

THIRDLY. It is certain that the northern lights are the highest of all meteors, though they sometimes extend pretty low into the inferior atmosphere; and Doctor Franklin's conjecture, that they proceed from electricity, is at present generally followed by all meteorologists. A detail of their reasons I must omit, as it would occasion too great a digression from the present subject.

FOURTHLY. It is certain that after the appearance of an aurora borealis the barometer commonly falls. This observation was first made by Mr. Madison in America*; and I have seen

* II. Phil. Trans. Philad. p. 142.

it verified in the diaries of the Berlin Academy for 1783 and 1784, the only ones which I have consulted. These meteors are also generally followed by high winds*, and usually from the south, all which strongly prove a rarefaction in the northern regions. These lights are much more common in the higher latitudes of North America than in the same latitudes in Europe. Captain Middleton remarks that they appear almost every night in Hudson's Bay, lat 59, whereas at Petersburg they are seen much more rarely ; which confirms my opinion that the superior effluence is more copiously distributed over North America than over the old continent.

* VIII. Phil. Transf. Abr. p. 463.